VOLCANOLOGY AND GEOCHEMISTRY OF THE ELLENDALE LAMPROITE FIELD (WESTERN AUSTRALIA).

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INTRODUCTION

The Miocene (20-22 Ma) Ellendale Volcanic Field (Western Australia) is located on the Phanerozoic Lennard Shelf, adjacent to the SW margin of the Precambrian Kimberley Block. The field consists of about 50 ultrapotassic volcanic bodies, subdivided into two main groups: ultrabasic olivine lamproites and more silica-rich leucite lamproites (JAQUES et al. 1986). Most of the Ellendale Field lamproites carry diamond: two olivine lamproite pipes contain subeconomic diamond grades and 3 other olivine lamproite pipes have average grades of 1 carat/100 tonnes or more whereas the leucite lamproites are either barren or contain only traces of diamond. This paper reports results of detailed geological, petrological and geochemical investigations of two olivine lamproites (Ellendale 4 and 9) for which extensive drill core material is available and two well exposed leucite lamproites bodies (Mt North and 81-Mile Vent). Detailed field mapping of the two leucite lamproites was carried out, with recording of flow banding attitutes in magmatic phases and cross and planar bedding dips in volcanogenetic sedimentary units.

VOLCANOLOGY

The detailed mapping and geological investigations support the general outline of SMITH & LORENZ (1989) who described the formation of maars at Ellendale in response to phreatomagmatic activity which probably started when lamproite magma, rising in a zone of structural weakness (feeder dike), reached the interface between relatively impermeable shales and siltstones of the Fairfield Group and the overlying sandstones of the Permian Grant Group which formed a high yielding aquifer. On eruption large amounts of detrital quartz grains from the then poorly consolidated Grant Group sandstones were ejected in addition to juvenile lamproite clasts. This induced repeated collapse of the wallrocks and the overlaying pyroclastic deposits. A small diatreme formed above which the maar crater rapidly grew laterally because of the low slope stability of the Grant Group sandstones. Whilst the diatreme continued to grow in depth, the maar crater increased in size due to further landslides and simultaneously sand-rich tuffs were deposited inside and outside of the crater. Massflow and landslide units with intercalated surge and fall, originally deposited on the crater floor, became part of the diatreme due to its subsidence.

In all four pipes investigated the stratigraphically higher tuff deposits have lower contents of accidental quartz grains than underlying units. This is attributed to the progressive drawing downward of the groundwater table within the Grant Group sandstones towards the more impermeable shales and siltstones of the Fairfield Group eventually resulting in the eruption of almost quartz-free tuffs when the diatreme root zone lay within the Fairfield Group. Deposits formed within the maar crater at this point are similar to earlier deposits - mainly mass-flow deposits with intercalated surge and fall

deposits - apart from a lower quartz content and a marked decrease in the number of landslide deposits of Grant Group sandstone which are rare or even absent (as in Mt North and 81-Mile Vent) in the upper tuff horizons. Thin intercalated scoria horizons observed in drill core imply that even during the main phreatomagmatic phase of maar formation groundwater access to the root zone was restricted several times. Eventually the root zone penetrated deeply into the Fairfield Group shales, supply of groundwater ceased, and explosive activity finally terminated.
Following a period of lava fountain activity magma rose within the diatreme and eventually filled the maar crater as either a lava lake (olivine lamproites) or lava dome (leucite lamproites), depending on the viscosity of the melt. At the pipes investigated in outcrop, the transition from phreatomagmatic to extrusive magmatic activity is marked by a phase of intense redeposition i.e. mass flow deposits. Simultaneous with, or immediately following emplacement of the magmatic core, the tuffs, especially those adjacent to the magmatic phase, were intruded by numerous small sills and dikes. Late-stage dikes and sills are most common in the leucite lamproite pipes where the intrusive rocks commonly are a composite of medium-grained lamproite and schlieren of fine-grained lamproite. Sills and dikes in the olivine lamproite pipes appear to be comparatively rare perhaps because of their different viscosity; alternatively, they may not have been recognized in the poorly preserved drill core material.

PETROGENESIS OF OLIVINE LAMPROITES
Petrographic differences within the investigated olivine lamproite pipes (Ellendale 4 and 9) are mainly restricted to in-situ cooling phenomena (e.g. crystallization of poikilitic phlogopite and K-richterite). However, small phlogopite phenocrysts, which are present in the tuffs of both pipes, became completely resorbed in the magma batches which subsequently formed the lava lakes, thus indicating low pressure reequilibration. Geothermometry and oxygen fugacity calculations based on olivine-spinel equilibria indicate crystallization of the tuffs and fine grained magmatic lamproites at temperatures (at 1 atmosphere) of 1050-1250°C under relatively reducing conditions (fO_2 at or slightly below the FMQ buffer). Inverse zoned olivines (forsterite rich rims) indicate an increase in oxygen fugacity during ascent, as predicted by FOLEY et al.(1986) as a consequence of dissociation of small amounts of H_2O, driven by H_2 loss. Spinel zoning, however, indicates oxidation only for the slowly cooled lava lake centers, where fO_2 became increased by 2-3 log units relative to the FMQ buffer. Much of the geochemical variation in Ellendale 4 appears to be due to significant (up to 25%) olivine fractionation (xenocrysts and phenocrysts) in the later magmatic phases. In contrast, Ellendale 9 shows much less variation in major element chemistry but significant variations in incompatible trace element abundances. The trace element abundances are not consistent with olivine fractionation but suggest an origin either by derivation of Ellendale 9 magmas by differing degrees of partial melting and/or small scale heterogeneities in their mantel source regions. Diamond distribution within Ellendale 4 and 9 pipes is not controlled by combustion or dissolution. The observed variation in diamond grade with specific units within each pipe is inferred to result primarily from fractionation (Ellendale 4) and a decreasing efficiency in sampling of the mantle source region by successive magma batches (Ellendale 9).

PETROGENESIS OF THE LEUCITE LAMPROITES

Petrographic differences within the lava domes of the investigated leucite lamproites are mainly attributed to intratelluric crystallization, since lithological boundaries (differences in phenocryst content and size) were found to be razor sharp (81-Mile Vent) or connected by a thin (about 1m) transition zone (Mt North). However, within the medium-grained part of the lava dome of Mt North in-situ crystallization produced small petrographic differences which are crossed by the magmatic flow banding.

The various petrographic units of Mt North and 81-Mile Vent are characterized by significant differences in their chemical composition, with the early formed units being richer in Si, Al, and K and poorer in Ti, Mg and Fe, relative to later units. Volcanological and petrographic evidence suggest production from a layered magma reservoir, where crystal fractionation, mainly of olivine, diopside, and an iron-titanium oxide phase but including small amounts of phlogopite and apatite, took place. However, in the case of Mt North the observed trace element pattern does not fit the model derived from the major elements. A decoupling of major and trace elements (including MgO and Ni) suggests operation of additional processes including entrainment of phlogopite and mixing of magmas with different trace element abundance and abundance ratios and possibly derived by different degrees of melting over different depth intervals.

The magma reservoirs for Mt North and 81-Mile Vent are inferred to have been located within the crust because the mineral compositions reflect formation at low pressures and the low pressure mineral assemblage is dominated by olivine with only minor phlogopite. Experiments on leucite lamproites (FOLEY 1989) show that olivine is a liquidus phase below 10 kbar above which it is replaced by phlogopite. Leucite, hercynite-pleonaste and corundum-bearing xenoliths are interpreted as partially molten crustal xenoliths incorporated in the melt within the magma reservoir. Olivine compositions and zoning together with olivine/melt equilibria, suggest that the magma chamber, at least for Mt North, was characterized by oxidizing conditions. This oxidizing environment in the magma chamber might explain the complete absence of diamonds at Mt North which is uncommon in the Ellendale Field.

Atkinson, W.J., Hughes, F.E., and Smith, C.B. (1984): A review of the kimberlitic rocks of Western Australia. In J. Kornprobst, Ed., Kimberlites 1: kimberlites and related rocks, p. 195-223, Elsevier, Amsterdam

Foley, S. (1989): The genesis of lamproitic magmas in a reduced fluorine-rich mantle. GSA S.P. No 14, 616-631

----, Taylor, W.R., and Green, D.H. (1986): The role of fluorine and the oxygen fugacity in the genesis of the ultrapotassic rocks. Contrib. Mineral. Petrol., 94, 183-192

Jaques, A.L., Lewis, J.D., and Smith, C.B (1986): The kimberlitic and lamproitic rocks of Western Australia. Geol. Surv. W.A. Bull., 132, 268 p.

Smith, C.B. and Lorenz, V. (1989): Volcanology of the Ellendale lamproite pipes. GSA S.P. No 14, 505-519

Stachel, T. (1990): The Ellendale Volcanic Field - Volcanology, petrography, and geochemistry of 4 pipes. Diss. Univ. Würzburg, Germany, 359 p.